ADVANCED SPACEPORT TECHNOLOGIES WORKING GROUP

BASELINE REPORT

November 2003

Charting America's Path Towards Low-Cost, Routine Access to Space

ASTWG

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Acknowledgements

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In addition, we wish to thank the participants of the Technology and Commerce Development miniretreats who contributed their ideas and energies to the overall vision. Through the hard work and dedication of the technology miniretreat participants, we now have capability roadmaps and identified key technologies that illustrate the future infrastructure needed for spaceports to operate with airportlike efficiencies. With equal dedication and passion, the Commerce Development miniretreat participants painted the picture of a robust space enterprise, which has never been documented before.

The following ASTWG members were contributing authors/collaborators:

Kevin Brown	*Command Control Technologies / Booz Allen Hamilton*
Kevin Connell	*Aerospace Development Center*
Ron Fussell	*Boeing*
Cris Guidi	*NASA Kennedy Space Center*
Tim Huddleston	*Aerospace States Association*
Scott Huzar	*NASA Kennedy Space Center*
Kevin Ingoldsby	*Lockheed Martin Space Systems*
Dr. Tim Kotnour	*University of Central Florida*
Carey McCleskey	*NASA Kennedy Space Center*
Janice Mendonca	*Research Triangle Institute*
Steve Ryberg	*University of Nebraska at Omaha*
Dr. Roelof Schuiling	*NASA Kennedy Space Center*
Bob Waterman	*NASA Kennedy Space Center*

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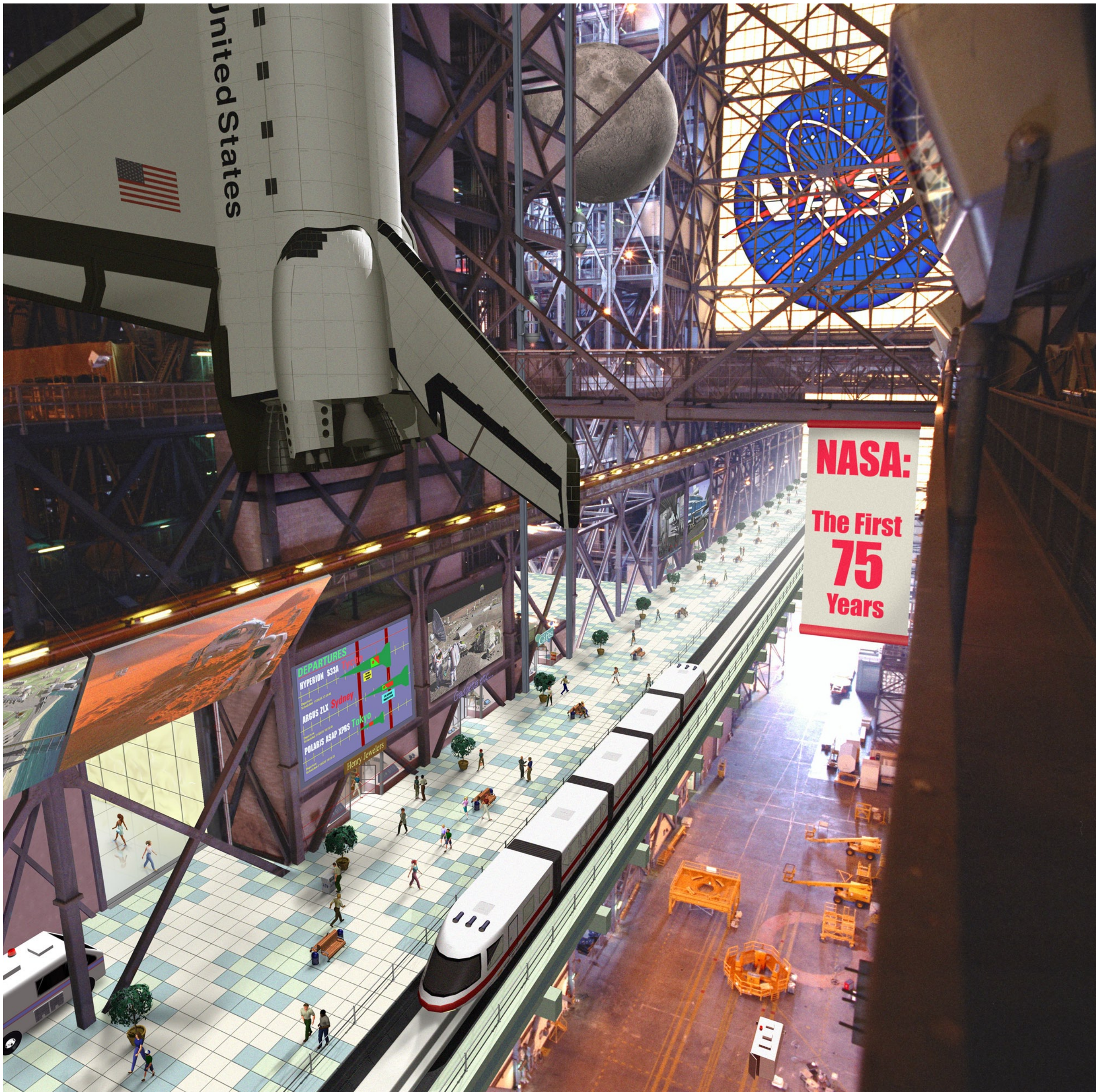
Cris Guidi
ASTWG Chair and Baseline Report Lead



Conceptualization of a future spaceport

Executive Summary

Space provides new exploration frontiers for the human spirit, and yet today, the United States continues to rely on old infrastructure and its laurels when it comes to space exploration. The 21st century is upon us, and it is now time to explore space and make space accessible to all walks of life. By providing this low-cost, safe, routine access to space, more substantial opportunities will be available to help the nation grow as a whole with commerce, technology, aerospace leadership, and new economic opportunities for every citizen.

The Advanced Spaceport Technology Working Group (ASTWG) grew iteratively in response to a desire that has been around for decades – to improve the efficiency of ground operations. ASTWG, with a membership of over 250 representatives of U.S. government, industry, and academia committed to improving space access, enables the exchange of information and fosters cooperation within the space access community to identify business and technology gaps and minimize duplication of technology development efforts. The goal of ASTWG is to collect all of the stakeholder requirements and develop national technology roadmaps for launch site operations technologies. These roadmaps will guide the stakeholders in prioritizing the specialized technologies required to achieve spaceport visions.

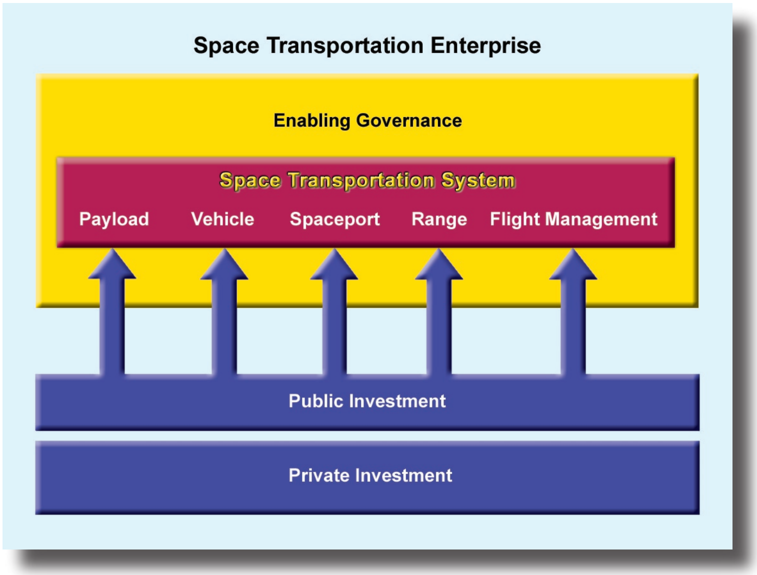
One method for identifying the necessary improvements is to document the ground operations required to process flight hardware and dissect the process into functions and subfunctions performed at a spaceport, similar to a functional breakdown structure. This Baseline Report, the result of that process, was developed over two years and is one of several ASTWG products.

The **ASTWG Baseline Report** provides an overall definition and description of a spaceport and the vision of an ideal spaceport. It also contains the ASTWG history, the functional capability roadmap for each spaceport function, the challenges and potential technical approaches associated with achieving the desired capabilities, and an introduction to the technology focus areas. The ASTWG Baseline Report will be reevaluated continually to ensure the vision is still relevant when compared to the present-day environment.

Throughout this report, we ask and answer key questions that help illustrate the importance of developing spaceports in the early part of this century. All the questions support an underlying quest – to improve our spaceports to support routine, cost-effective access to space.

Why pursue space?

Space access will affect every American in some fashion because it ultimately improves the quality of life for all by enabling economic growth, national health, empowered people, a sustainable planet, and national security. These factors are promoted by low-cost, routine, and reliable access to space, which is a key feature of a national space enterprise. Low-cost space access will provide the fertile ground to grow economies that will nourish the nation and sustain a future leadership in world commerce. For the space enterprise to be successful, a robust space transportation enterprise (consisting of the space transportation

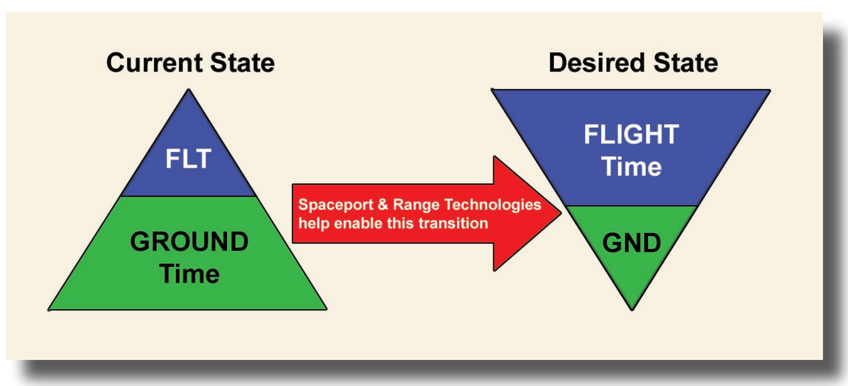


Spaceport transportation enterprise

system, the enabling governance, and public and private investment) must exist.

A robust space transportation enterprise must focus on reducing the cost of spaceflight to ensure growth in the space markets. Challenging goals ("reductions as great as 50 percent for the cost and time to access space and the transit time between two points in space"[1]) have been identified in hopes of making access to space affordable, with the thinking that demand will drive down cost. But only limited success has been realized to date toward meeting those goals.

To achieve such performance measures, a significant operational paradigm shift at the spaceport must occur. The overarching goal is to shift the current operational scenario to one that has efficiencies and reliability similar to the aviation industry. Today in the Space Shuttle program, an incredible amount of time and resources is spent processing the vehicle and payloads on the ground with comparatively little flight time. In the future, the target is to reverse that paradigm and spend minimal resources and time on the ground and much more time in flight, the way airlines operate today. This can only be accomplished if we start designing a space transportation system from a macro- or high-level perspective and then focus on the individual space transportation system components.



Operational paradigm shift

Although all elements of the space transportation system need to be addressed to achieve low-cost, routine access to space, this report concentrates on the architecture, infrastructure, and operations of the space transportation system, collectively known as the spaceport.

[1] White House Office of Science and Technology Policy, *Fact Sheet: White House Completes Review on Space Launch Ranges*, February 8, 2000, <http://www.ostp.gov/html/0029.html> (October 20, 2003).

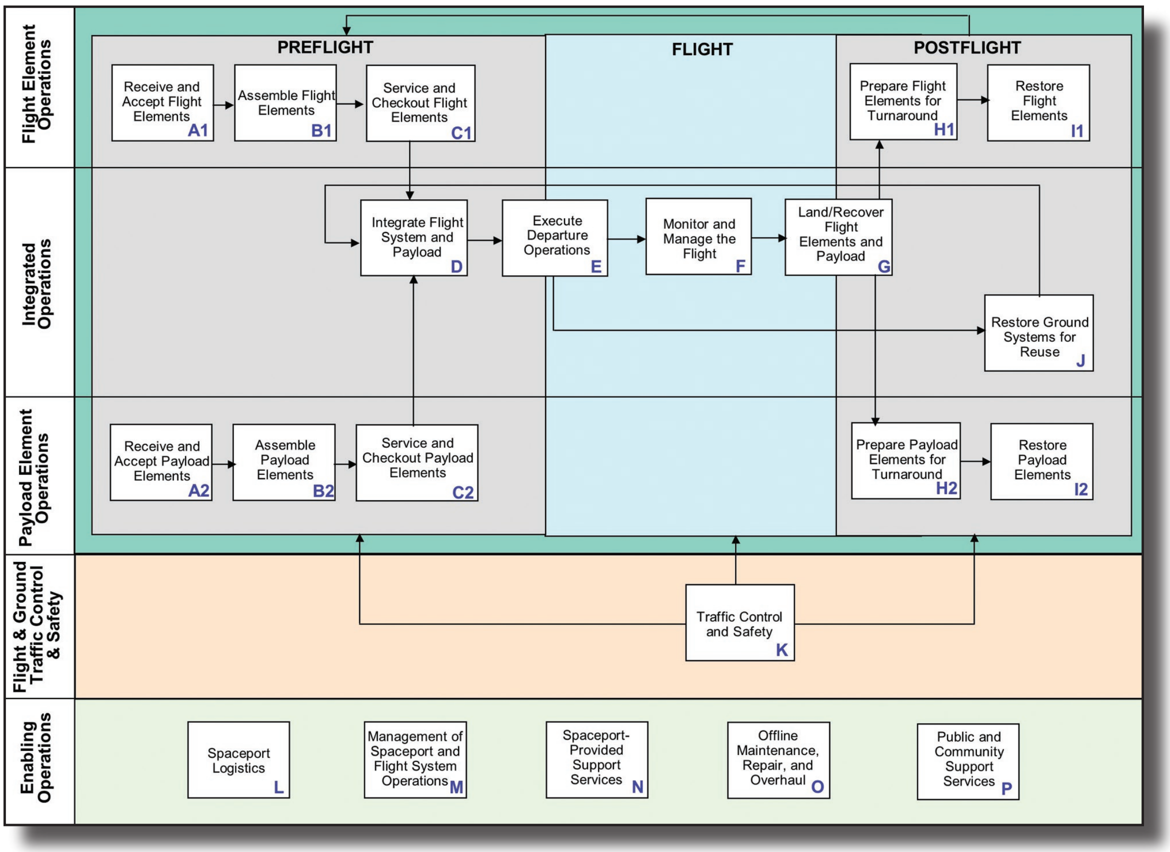
What is a spaceport?

A spaceport is the infrastructure at either the origin or destination of a spaceflight. It provides the essential infrastructure and related ground processing operations needed for space access as well as the facilities, organizations, and operations required to safely manage spaceflight. The spaceport serves as a node in a multimodal transportation network. The community is a vital component of the spaceport environment, as are the key spaceport players: the spaceport operator, launch vehicle operator, payload customer, and launch vehicle manufacturer.

Spaceport functions are organized into five operational phases:

- **Flight Element Operations** prepare the space transportation vehicle elements for flight and include receiving/acceptance, final assembly of the vehicle elements, servicing of those elements, and postflight vehicle operations (turnaround and maintenance).
- **Payload Element Operations** assemble, integrate, and test payload elements in preparation for the mission and include preparing passengers/flight crew for their trip and any postflight operations required.
- **Integrated Operations** integrate the flight vehicle and payload for departure. This includes in-flight support, landing/recovery, deintegration, restoration, and ground support systems turnaround.
- **Flight and Ground Traffic Control and Safety Operations** provide independent safety oversight for air and space transportation operations sharing global airspace and low Earth orbit.
- **Enabling Operations** support spaceport infrastructure and include logistics, management, support services, maintenance, and interfaces to the community.

The following figure depicts the organization of these five operational phases within the generic spaceport operations model. The table maps that model to the vision of ideal spaceport operations provided by the Plug & Play model.



Generic spaceport operations model

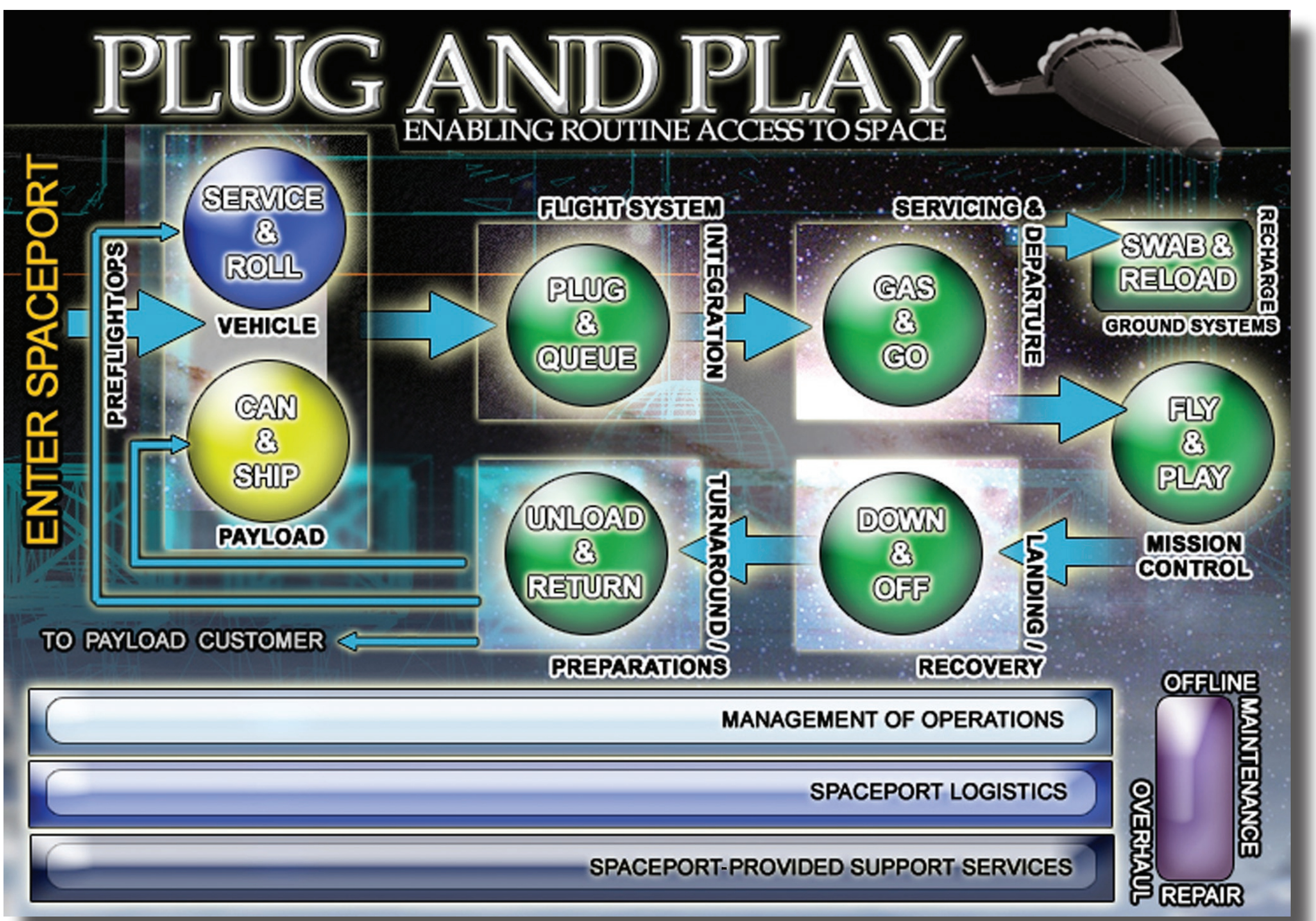
Mapping of generic spaceport operations model functions to Plug & Play model

Functions **Plug & Play Phase**	**Definition**	**Key Characteristics**
Flight Element Preflight Operations Service & Roll	Minimal servicing and/or routine, scheduled turnaround that replenishes consumables only and performs a power-up diagnostics test to quickly reveal faults and anomalies without user interaction.	• Minimal servicing of the flight element • Self-diagnostics with autonomous repair
Payload Element Preflight Operations Can & Ship	Containerized payload that is self-sufficient (does not rely on vehicle for its resources) and has standard interfaces for integration to the flight vehicle.	• Self-sufficient containerized payloads • Standard interfaces • Automated calibration and self-fault identification • Minimal payload servicing
Integration of Flight Element and Payload Element Plug & Queue	Simple and standard interfaces that allow for autonomous and rapid integration using common lift points, self-aligning surfaces, autonomous umbilicals, and self-fault isolation and repair techniques.	• Automated integration • Self-verifying interfaces • Self-fault isolation and repair • Autonomous hardware recognition and reconfiguration
Execution of Departure Operations Gas & Go	On-demand fluid servicing of the flight vehicle and/or payload and quick verification that vehicle is ready to fly.	• Clean pad/runway • On-demand propellant system • Autonomous umbilical extend and retract • On-board control of preflight operations • Skeleton crew for departure operations
Monitor and Manage the Flight Fly & Play	Flexible and responsive flight operations control.	• Fleet operations • Separation of flight ops from mission ops • “Free Flight” • On-orbit traffic coordination
Restore Ground Systems for Reuse Swab & Reload	Robust spaceport ground systems with informed maintenance where status of systems is communicated via power-up diagnostics test that quickly reveal faults and anomalies. Repairs and retests are remotely or autonomously performed without direct user interaction.	• Available on-demand ground systems • Self-restoring ground systems • Robust ground systems
Land/Recover Flight and Payload Elements Down & Off	Routine reentry, landing with self-safing systems, rapid removal from runway, and deactivation of landing support systems.	• Spaceport autonomous safing/reconfiguration of the flight vehicle • Autonomous data archive • Quick exit of landing area
Turnaround Preparations of Flight Element and Payload Unload & Return	Informed maintenance where status of vehicle is communicated to spaceport via power-up diagnostics test to quickly reveal faults and anomalies without user interaction.	• Informed maintenance
Spaceport Logistics Assist & Enable	Efficient, automated, integrated logistics operations that provide effective support for spaceport host, operators, and customers.	• Automated supply chain management • Integrated with vehicle/system health management systems • On-demand materials availability for operators
Management of Spaceport and Flight Operations Make it Happen	All the underlying planning and management that will provide spaceport customers the seamless, transparent service they expect in the course of business.	• Self-service customer interface • Global master planning • Operations and management systems seamlessly integrated and transparent to the customer
Spaceport-Provided Support Services Protect & Support	Mitigation risks to the spaceport and its host community, informing and educating spaceport customers and the general public, and providing expected consumer accomodations and services.	• Just-in-time performance support • Real-time, proactive environmental mitigation – no-waste spaceport • Autonomous surveillance • Seamlessly integrated with global spaceports and customers • Microeconomy within spaceport
Offline Maintenance, Repair, and Overhaul Repair & Refurbish	Rapid, automated, self-triggered techniques that quickly restore vehicles and ground systems to reliable online service.	• Nonintrusive testing with self-inspecting systems • Self-healing structures and systems • Little or no reassembly • Self-test and healing

What is an ideal spaceport?

The key operating characteristics for a spaceport focus on interoperability, ease of use, flexibility, safety/environmental protection, and multiple concurrent operations. The long-term vision is to have airportlike spaceport operations. Airportlike refers to high flight rates and the accommodation of multiple vehicle architectures without significant reconfiguration of the infrastructure after each mission. The transition of a space vehicle through the National Airspace System will be seamlessly integrated, causing minimal disruption in the current air traffic control system. The turnaround times of the vehicles will be on the order of hours.

Today the ideal spaceport is defined in a vision, but tomorrow spaceports will become vital hubs ushering in a revolution in transportation. The number of spaceports will increase as space transportation becomes reliable and affordable, and spaceports will handle a growing variety of vehicles. The Plug & Play model depicts the ideal condition where a range of vehicle architectures and payload customers can seamlessly integrate into the spaceport operations. Extensive reconfiguration of hardware and/or infrastructure is not required to accommodate different vehicle or payload designs. It is envisioned that the spaceport will integrate a vehicle or payload in much the same way a computer recognizes new hardware attached to it and installs the drivers necessary to use it.



Plug & Play vision of spaceport operations

The Plug & Play vision is a synthesis of contemporary spacecraft processing and commercial airport operations. Elements of the preflight and postflight ground operations were examined for both existing spaceflight vehicles and airport operations in an effort to identify common themes or ideals.

A progression of near-, mid-, and far-term capabilities as shown in the following figure will be required to realize the Plug & Play vision of ideal spaceport operations.

Near-Term:

- High flight rate of a single architecture
- Standardized servicing ports and interfaces
- Standard payload carrier
- Common/universal lifting GSE
- Control software development based on abstract interfaces
- Control software for automatic propellant loading
- Enhanced remote sensing for vehicle safety after landing
- Paperless integrated logistics systems
- Centralized data repository – integrated databases
- Enhanced information/ communication architecture
- Integrated emergency services

Mid-Term:

- Multiple vehicles from common spaceport infrastructure
- Common standards between vehicle and spaceport
- Containerized payloads
- Robotic support for lifting operations
- Spaceport interfaces recognize flight system connected
- Automated servicing operations
- Automated safing/ reconfiguration of vehicle and payload after flight
- Automated and integrated paperless logistics system
- Automatic interactive scheduling of flight vehicle, ground support facilities, and support logistics
- Integrated communication system linking several spaceports
- Semiautonomous surveillance

Far-Term:

- Airportlike operations
- Minimal servicing with self-diagnosis and autonomous repair
- Piggyback payloads – self-sufficient; noninvasive to vehicle
- Minimal facility/vehicle interfaces
- On-demand propellant loading operations
- Autonomous safing/ reconfiguration after landing
- Automated paperless supply chain management integrated with equipment integrated health management
- Business systems and processes integrated into one data management system
- Autonomous, adaptive self-training scheduling system for flight vehicle, ground facilities, and support infrastructure
- Global connectivity to spaceports
- Autonomous surveillance

Overall spaceport system capabilities goals

How do we make this vision a reality?

The more efficient and economical spaceport operations depicted in the Plug & Play vision can be realized by infusing new technologies into ground support systems in the following technology focus areas (TFAs):

- **Advanced Servicing Technologies:** This TFA involves fueling, purging, and loading/replenishing the vehicle/payload consumables. Its goal is to enable safe, rapid, on-demand servicing operations. Accomplishment requires the development of advanced servicing processes and propellant systems/components. Autonomous operations are of critical importance to improve safety by isolating hazardous operations from the workforce. Advanced servicing technologies will pursue vehicle interface system, production, storage and distribution, recovery and disposal management, and safety and monitoring systems.

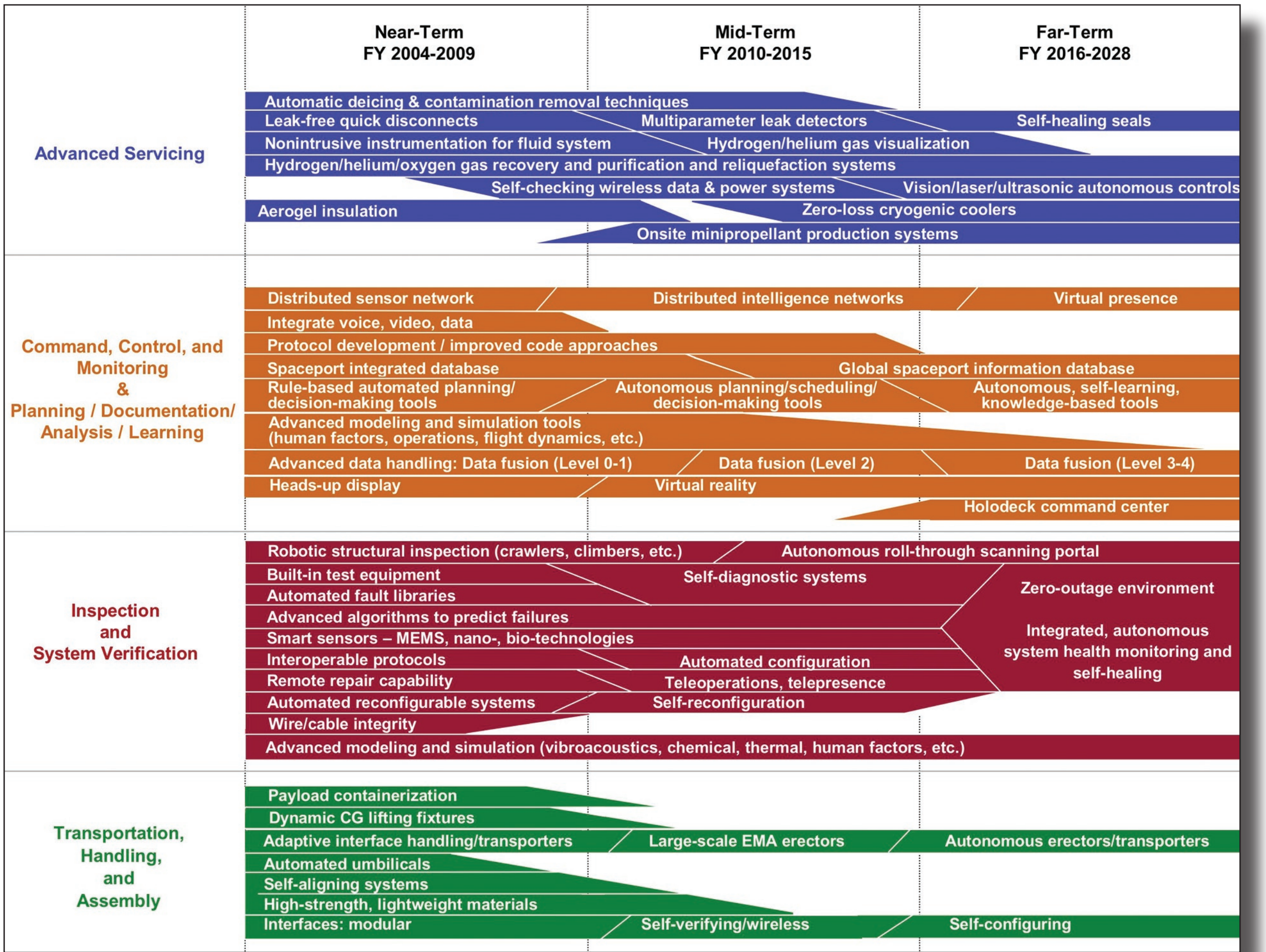
- **Command, Control, and Monitoring:** This TFA provides the infrastructure to control the vehicle and spaceport support systems. This control follows the data from the sensing element to the decision maker and then follows the resulting commands all the way to the affected component. The goal of this TFA is to reduce the cost of this infrastructure while increasing safety and augmenting human performance. Command, control, and monitoring will pursue technologies in the areas of data/information display, data processing and handling, advanced modeling and simulation, system commanding and verification, and advanced communication systems.

- **Inspection and System Verification:** System reliability and structural integrity of flight elements, as well as critical ground systems, ensure successful vehicle operations and public safety for each mission. These conditions are achieved by comprehensively inspecting and testing the systems and hardware. Because of the diverse nature of the vehicles and hardware supported by the spaceport, a variety of test and inspection scenarios must be accommodated. The goals of this TFA are to minimize the time and resources required for this activity, to eliminate the need for redundant tests and inspections, and to increase the probability of mission success and safety. Inspection and system verification will develop technologies that perform noninvasive field inspections, self-fault isolation and repair, and launch environment protection and mitigation techniques.

- **Transportation, Handling, and Assembly:** The goal of this TFA is to expedite the movement and precision positioning of flight and payload elements, while ensuring the safety of the workforce and hardware. Equally important objectives are to reduce the human interface and help the workforce accomplish repetitive hazardous tasks, such as lifting and assembly operations, efficiently and safely. Transportation, handling, and assembly will develop advanced mobility, alignment, handling, and positioning systems for rapid flight element integration.

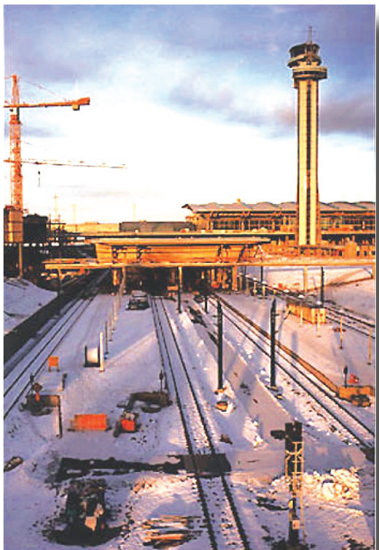
- **Planning, Documentation, Analysis, and Learning:** The efficient management of information is paramount in the operation of the advanced spaceport. The timely availability of information allows for rapid and effective reaction of the business enterprise, as well as technical systems, to changes in the operational environment. The goals of this TFA are to reduce costs by optimizing data processing and information management and to improve operational parameters in scheduling and tasking through analysis and learning. Planning, documentation, analysis, and learning will develop advanced information technologies for autonomous data collection (e.g., vehicle health, ground system health, work execution, configuration management), active decision support, constraint-based planning and scheduling, and financial management.

An extensive number of key technologies contribute to the Plug & Play vision of providing low-cost, routine, safe access to space. Of this large set of technologies, many cross technology focus areas and apply to disciplines other than space access. Some technologies will be government-unique or not commercially available. It then becomes the responsibility of the federal government to develop these technologies to enable the overall vision. The following roadmap highlights the key technologies that will foster the standardized yet flexible spaceport architecture of the future. This roadmap is not intended to be all-inclusive but rather to document the enhancing and enabling technologies for pursuit of development. The command, control and monitoring technologies and the planning, documentation, analysis, and learning technologies have been combined because of their similar elements. The follow-on technology plan will address these two TFAs as one.



Key spaceport technology development roadmap

What steps does ASTWG recommend for advancing America's spaceport industry?



1. *Establish a national investment priority for developing a global spaceport infrastructure network.*

ASTWG recommends formulating a concept of operations that provides the vision and path for developing this next generation of space transportation infrastructure. The concept should accommodate transportation to and from space, point-to-point travel on Earth, and travel between space station orbital facilities. The concept should provide for an independent, government-operated safety and coordination function for space traffic control; standardization requirements that will foster industrial growth through free-market competition; communication and data exchange protocols; licensing and certification; payload and vehicle selection; environmental protection; international operations; abort, emergency, and contingency operations; and other essential aspects of a global space transportation system open to all suppliers and consumers.

2. *Formulate a national technology program for spaceports and ranges.*

ASTWG recommends formulating a national technology program that will develop a national strategic plan and investment strategy to identify near-term technology projects and demonstrations that directly address some of the challenges of the far-term vision. This national technology program would encompass multiple government agencies in partnership, identifying the common needs among the agencies toward this overall vision. Such a technology program must address the entire spectrum of technology development from basic research to the capture of ideas to prototype engineering for technology demonstration, a process that advances technology readiness for full implementation into an operational system.

3. *Develop and advocate standards for ground operations and launch systems and infrastructure.*

ASTWG recommends that spaceport developers work together to develop a robust system that is capable of handling a multitude of vehicles. If the vehicles of tomorrow have hundreds or even scores of unique interfaces, they will see flight rates as low as the Space Shuttle sees today. At the same time, spaceports cannot demand that there be only one or two interfaces since technology drives that number. In the beginning of new spaceports, substantially more interfaces will be needed, but in the following years as technology develops, this number will be dramatically reduced.

4. *Generate customer-friendly space transportation policies and regulations.*

ASTWG recommends strictly regulating space transportation in the early stages, as airlines were, to help develop the industry in its adolescence. As the industry matures, the following additional steps should be considered:

- **Separate vehicle manufacturers from spaceport and vehicle operators** to prevent conflicts of interest and promote improvements in productivity and performance through free-market competition.
- **Deregulate the space industry once it can sustain itself** to create a diversified, competitive marketplace largely governed by free-market principles.

5. *Educate the public and future explorers about the benefits of space exploration and utilization.*

ASTWG recommends focusing citizen education efforts in four areas: K-12 education, postsecondary education, higher education (colleges and universities), and informal education. For spaceports to flourish, each new generation needs to be educated about space and how it can directly benefit them. Making people aware of market opportunities enabled through such a medium is essential to the development of the thriving spaceport enterprise. Developing and sustaining an educated and competent workforce is crucial for the spaceport enterprise to succeed.

NASA Hubble telecope image of a grazing encounter between two spiral galaxies.

What have we learned and what comes next?

- **Space can help the United States answer its national imperatives but only if we make space access affordable and safe by sustaining advances in technology and standardizing the space transportation industry.**

  Future space capabilities will depend upon the technology advances we make today as a nation. Revolutionary reductions in the cost and time required to access space will not be realized without significant technological breakthroughs in ground processing, launch operations, and air traffic control/range operation systems. Developing standardized processes and interfaces, as airports did, and applying them to emerging spaceports will reduce costs and increase the ratio of flight time to ground processing time.

- **We can make this happen by educating our citizens about the benefits that can be derived from space and committing the national investment necessary to develop a commercially self-sufficient space transportation enterprise.**

  What ASTWG has developed in the last two years is a national consortium for spaceport technology, in and of itself a more valuable asset than the reports and recommendations it produces. As the nation looks to the future for technology and policy on issues concerning spaceports and ranges, ASTWG is poised to offer information and advice, a comprehensive perspective and continuing forum, and consensus for the path we should take. From the forefront of emerging technologies and developing spaceport architectures, ASTWG will track and help guide our progress and encourage the United States government and its citizens to devote the vision and resources needed to allow space and its benefits to improve our everyday lives.

For more information, contact Cristina Guidi, <Cristina.Guidi-1@nasa.gov>, (321) 867-7864.